1. INTRODUCTION

Suburban sprawl, population growth, and auto-dependency have, along with other factors, been linked to air pollution problems in U.S metropolitan areas. Accordingly, the Clean Air Act and other federal legislation and regulations require metropolitan areas to develop strategies for reducing air pollution in those cases where air quality standards are exceeded. An emissions 'budget' is established in these metropolitan areas that provides a benchmark for comparing new emission-generating activity, and presumably not exceeded. Such a goal becomes difficult when trying to accommodate the needs of a *growing* population and economy while simultaneously *lowering* or maintaining levels of ambient pollutants. Growing urban areas must, therefore, continually develop creative strategies to curb increased pollutant production. Because the largest contributor of pollutant emissions in urban areas has most often come from transportation (or mobile) sources, transportation is targeted for new control strategies.

Developing measures of effectiveness and subsequent predictions of overall impact for control strategies require an understanding of the relationship between *observable* transportation system characteristics and emission production. Quantifying this effectiveness requires modeling these relationships. According to published research, motor vehicle emission rates are correlated to a variety of vehicle characteristics (weight, engine size, emission control equipment, etc.), operating modes (idle, cruise, acceleration, and deceleration), and transportation system conditions (road grade, pavement condition, etc.) [Guensler, 1994, Barth, 1996]. Exhaust emissions are produced when a vehicle is started and when it is in operation. Pollutants produced from starting a vehicle can be predicted using vehicle characteristics. Running exhaust emissions additionally require estimates of dynamic engine conditions that result from how the vehicle is driven. Estimating motor vehicle emissions requires the ability to predict or measure these parameters for an entire region at a level of spatial and temporal aggregation fitting the scope of control strategies. Current modeling approaches, however, do not have the capability to provide these estimates.

Today's motor vehicle emission modeling process is based on four separate models: a travel demand forecasting model, a mobile emission model, a photochemical model (for emission inventory), and a microscale model (for analyzing transportation improvements). The travel demand-forecasting model uses characteristics of the transportation system and socioeconomic data to develop estimates of road-specific traffic volumes and average speeds. Mobile emission models use these travel demand estimates, operating fleet model year distributions, and environmental conditions to develop estimates of mobile source pollutant production. These estimates are fed into photochemical models (along with stationary source estimates and data regarding atmospheric conditions) and are used to predict ambient pollutant levels in space and time. These mobile source estimates can also be used by microscale models to predict pollutant levels near specific transportation facilities.

There are several problems with the four-model system that limit effective evaluation of motor vehicle emission control strategies. First, the estimates of vehicle activity (vehicle miles traveled and average speed) lack the accuracy and spatial resolution needed to evaluate control measures [Stopher, 1993]. Second, the mobile source emission rate modeling process uses highly aggregate fleet estimates and average emission rates which are not specific for the fleet in operation, mode of vehicle operation, or grade of the highway facility. As a consequence, the current modeling system has limited capabilities for meeting the modeling requirements of transportation planners. Transportation planners and environmental assessment and control officials have need for improved models that help identify the impacts of standard transportation system improvements (e.g., lane additions, signal timing, peak-hour smoothing).

While many researchers agree that new models and processes need to be developed to overcome these problems, there is disagreement over the best approach [Washington, 1996]. The U.S. Environmental Protection Agency and the Federal Highway Administration held a workshop in Ann Arbor, Michigan in May, 1997 for the purpose of identifying and discussing current emission modeling research efforts [Siwek, 1997]. After the workshop, it was clear that defining appropriate model aggregation levels is important in defining how and what research should be conducted. A point of departure between the largest vehicle emissions research efforts (University of California at Riverside, and the Georgia Institute of Technology) and the currently mandated approach (MOBILE5a) is the level of aggregation required. Figure 1.1 demonstrates the spectrum of possible approaches. The figure shows that highly aggregate approaches limit explanatory power, but have reduced data intensity. Disaggregate models have the most explanatory power, but the highest data needs. An added dimension to the issue is the fact that estimates must be spatially and temporally resolved, suggesting that an undefined level of spatial and temporal aggregation must also be defined. In fact, the level of spatial and temporal aggregation of mobile source emissions needed by photochemical models may help define the minimum level of model aggregation currently being debated.

This report presents a *research* model that can guide future mobile emissions model development efforts. A major objective of the model is to incorporate the latest transportation / air quality findings at a low level of spatial aggregation (restricted only by data availability). By creating a model under these guidelines, information is developed that leads to the maximum level of disaggregation given user needs and data availability. The research model will be comprehensive, flexible, and user-oriented. It includes enhanced vehicle activity measures; starts, idle, cruise, acceleration, and deceleration. Vehicle technology characteristics (model year, engine size, etc.) and operating conditions (road grade, traffic flow, etc.) are developed at a large scale (small zones and road segments). Flexibility is achieved through a modular design that separates emission production based on thresholds determined in background research. Due to large gaps in the state of knowledge, technology, and practice regarding travel behavior, emission rates, and the urban system inventory, the accuracy of the model results remains unvalidated and therefore unknown. However, the model contributes to transportation and air quality research in that it aids research and software development endeavors.

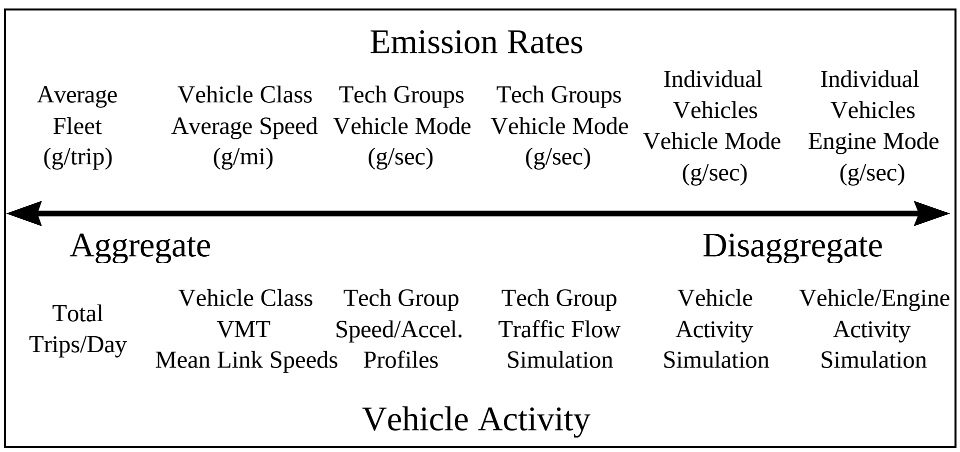

Figure 1.1 - Emission Modeling Spectrum (tech groups refer to sets of vehicles with similar emission characteristics)

The intended model users include emission science experts, model developers, transportation planners, policy makers, and governmental researchers. Each user group has specific modeling interests that define how the model should be designed and presented. Central to the model design is a geographic information system (GIS). Geographic information systems are widely used computer tools that allow geographically referenced data to be organized and manipulated. Both transportation and air quality vary in spatial dimensions. Thus, GISs have the conceptual capability to manage the relationships between transportation activity and resulting air quality changes based on their spatial characteristics. Further, GISs are already used by most planning organizations and government institutions. Thus, a GIS-based emissions modeling framework fits the character of emission science as well as fitting the technical environment of the expected users.

The variables included in the proposed research model are those whose relationship to vehicle activity and emission rates has been defined in research and available to public agencies (see below). They can be categorized as follows:

Spatial Character:

- *US Census block boundaries*
- *Land use boundaries*
- *Traffic analysis zone boundaries (from travel demand forecasting model)*
- *Grid cell boundaries (defined by user)*
- *Road segments (by classification)*
- *Travel demand forecasting network links*
- *Grade school and university locations*

Temporal Character:

- *Hour of the day*

Vehicle Technology:

- *Model year*
- *Engine size*
- *Vehicle weight*
- *Emission control equipment*
- *Fuel injection type*

Modal Activity:

- *Idle*
- *Cruise*
- *Acceleration*
- *Deceleration*

Trip Generation:

- *Home-based work trips*
- *Home-based shopping trips*
- *Home-based university trips*
- *Home-based grade school trips*
- *Home-based other trips*
- *Non-home-based trips*

Road Geometrics:

- *Number of lanes*
- *Grade*

Socioeconomic characteristics (for spatial allocation only):

- *Housing units*
- *Land use (residential, non-residential, and commercial)*

1.1. Summary of Contributions to Research

- *An automobile exhaust emissions model is developed maximizing comprehensiveness, flexibility, and user friendliness.*

Comprehensiveness is accomplished through the inclusion of variables and procedures identified in the literature as significant to emission rate modeling. Flexibility is achieved by organizing the model components by geographic location, and by maintaining a modular program design. User friendliness is achieved by including only current data available to planning agencies, and by using a GIS framework.

- *A research tool is provided that allows for the testing of variable levels of motor vehicle emission model spatial aggregation.*

By having the flexibility to use a variety of spatial entities, the model can become a 'testbed' for determining the spatial resolution needed for future models. This information is valuable in identifying future research needs, costs of emission estimation, model development, maintenance, and operation. A question this model could be used to help answer would be, "Given the current state of research, does a 1 sq. km aggregation of ozone precursors provide enough resolution to predict ozone formation, or would a 4 sq. km aggregation be better?"

- *The benefits of using GIS for emissions modeling are demonstrated.*

GISs provide the ability to organize data by location, in turn providing the capability to develop relationships with new or existing spatial datasets. This allows for the development of creative alternatives to model construction and provides the ability of prioritizing emission control strategies based on location.

- *Research and data needs for improved spatial and temporal emissions modeling are identified.*

A study of background research into emissions modeling coupled with an analysis of data available in Atlanta will determine gaps in important emission-specific variables. Further, a prioritization of the data needs based on balancing explanatory power and cost will guide future model development.

1.2. Report Organization

Chapter 1 presents introductory discussion of the research, providing a list of: significant contributions, modeling components, and modeling approach.

Chapter 2 discusses background research significant to automobile exhaust emission modeling, vehicle activity modeling, and geographic information systems. This chapter identifies a research foundation of knowledge that is used to develop model parameters.

Chapter 3 presents a conceptual model design that serves as the foundation of the research approach. Accuracy, comprehensiveness, user needs, and enterprise awareness are important considerations in developing this conceptual model.

Chapter 4 provides a physical model structure that can be used as a research tool. The model will reside in a UNIX operating system and use *Make*, the *C* programming language, and *ARC/INFO*. A step-by-step guide to model use is also provided in this chapter.

Chapters 5 and 6 analyze a model implementation for a 100 sq. km area in Atlanta. Each module of the system is studied using sensitivity analysis, or through comparison of observed data

Chapter 7 will discuss data needs and present final conclusions. An expanded model diagram will demonstrate how future vehicle types and operating modes can be added to the system.

Chapter 8 lists references cited in the report, and Appendix A is a data dictionary.